DISCUSSION OF THE GEOLOGIC NON-SUITABILITY OF THE U.S. DEPARTMENT OF ENERGY'S SE-5 AREA FOR DISPOSAL OF HIGH-LEVEL RADIOACTIVE WASTE: A SUPPLEMENT TO THE GEOLOGY OF THE SANDYMUSH AND CANTON QUADRANGLES, NORTH CAROLINA

by

Carl E. Merschat and Leonard S. Wiener

SUPPLEMENT TO BULLETIN 90

NORTH CAROLINA GEOLOGICAL SURVEY

DIVISION OF LAND RESOURCES

DEPARTMENT OF NATURAL RESOURCES
AND COMMUNITY DEVELOPMENT

RALEIGH
1988

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INTRODUCTION

Safe disposal of waste radioactive materials is a significant problem of our age. Aside from social questions, which are certainly complex and of major concern, the technical challenge is to isolate hazardous nuclear waste from humanity for long into the future, perhaps even a millennium or more. Deep burial of waste is considered to be one feasible solution to the technical problem. Indeed, the Nation's Nuclear Waste Policy Act of 1982 authorized and mandated the U.S. Department of Energy to identify places in the country that have potential for the safe burial of high-level radioactive waste.[1] One of the requirements of the Act was for the Department of Energy to investigate potential burial sites in the eastern United States that fit the category of "crystalline rock".

In January 1986, the Department of Energy announced selection of twelve areas in crystalline rock as "proposed potentially acceptable sites" for disposal of high-level nuclear waste (figure 1). One of these areas is in western North Carolina and was designated "Candidate Area SE-5" (figure 2) (U.S. Department of Energy, 1986, p. 3-577).[2] Subsequently, with the strong support and encouragement of local residents and groups, the State's Geological Survey began a detailed, field-based mapping project of the area in March 1986. In June, the Department of Energy announced an indefinite postponement of its crystalline rock program. However, the State's geologic investigation continued, although for convenience the boundaries of the detailed study area were adjusted to coincide with the limits of the Sandymush and Canton 7.5-minute Quadrangles. These two adjoining quadrangle maps cover 122 square miles and include the central and major part of the irregularly bounded Department of Energy site. After the June postponement, both Congress and the Department of Energy reconsidered the need and practicality of an eastern United States repository. Finally, in December 1987, federal legislation effectively abandoning this aspect of the Nation's nuclear waste program was approved. By this time, the North Carolina Geological Survey's field and laboratory work was completed. The final scientific report, including detailed geologic maps of the two quadrangles, was published in 1988 (Merschat and Wiener, 1988).

The field-based investigation provides basic, factual data showing that local geologic conditions do not meet the criteria for acceptability as a high-level radioactive waste repository. In the following pages, geologic requirements for a safe repository are compared on a point-by-point basis with actual properties of the site as now documented by the detailed field investigation (Merschat and Wiener, 1988).

The Department of Energy's area SE-5, located in Buncombe, Haywood, and Madison

[1] High-level radioactive waste is produced by nuclear reactions that take place in the fuel of commercial and military defense reactors. It is characterized by high-level radiation from isotopes that decay relatively rapidly. Some high-level waste may also contain transuranic elements that have long half-lives.

[2] Through misconception of Blue Ridge stratigraphy, most of the area's rocks were termed "Elk River Complex" by the Department of Energy. As this terminology is neither formally established, nor even appropriate for much of the strata in the region, it is not used in this report.

Counties, extended over 105 square miles and covered parts of six, 7.5-minute quadrangles (figure 2). The centrally located Sandymush and Canton Quadrangles include nearly three-fourths of the area. About 11 percent lies east of these quadrangles on the Leicester and Enka Quadrangles, and about 16 percent is to the west on the Fines Creek and Clyde Quadrangles.

DESIGN CRITERIA

Crucial to safe interment of radioactive waste is the integrity and stability of the enclosing rock. In proceeding with its assignment, the Department of Energy developed a definition or set of criteria to describe an acceptable crystalline rock. The final definition is technically specific and detailed, and is reasonably conservative for the mandated purpose. As stated in the Final Southeastern Regional Geologic Characterization Report (U.S. Department of Energy, 1985, p. 1-1):

"Crystalline rocks" are defined by CRP (Crystalline Repository Project) as intrusive igneous and high-grade metamorphic rocks, rich in silicate minerals, with a grain size sufficiently coarse that individual minerals can be distinguished with the unaided eye.

"Metamorphic rocks are included if they can be characterized as:

(1) having been metamorphosed to upper amphibolite facies grade (e.g., sillimanite plus potassium feldspar);

(2) exhibiting chiefly granoblastic texture (nonschistose); and

(3) forming a cartographic unit consisting of mixed lithologies, having less than 50 percent marble, calc-silicate, and pelitic schist or schist with amphibolite."

To allow for the anticipated volume of waste material, the Department of Energy's proposed design required the underground excavation to

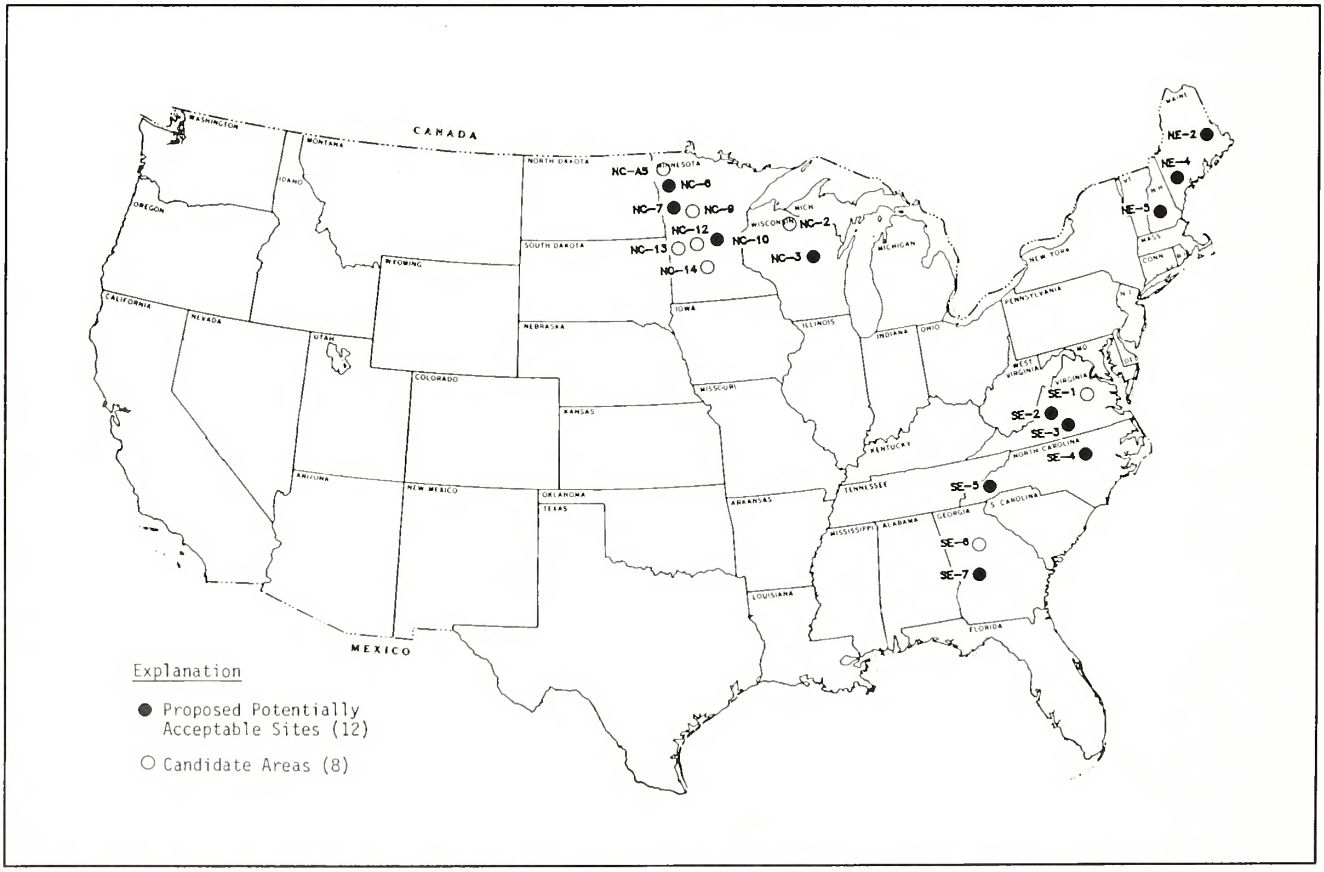

Figure 1. Location of the Department of Energy's proposed crystalline rock sites (U.S. Department of Energy, 1986).

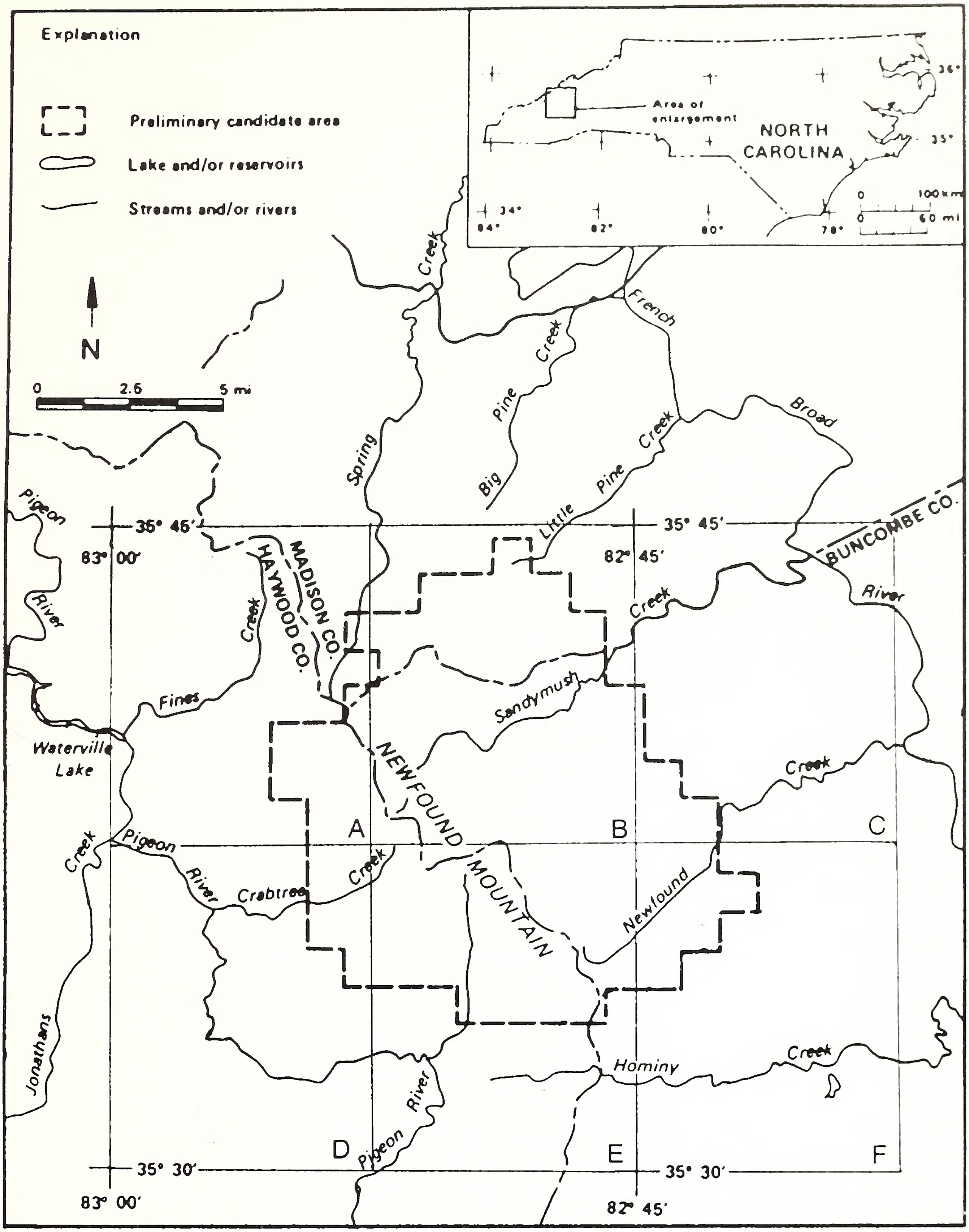

Figure 2. Location map of the SE-5 area in western North Carolina (U.S. Department of Energy, 1986). Seven- and one-half-minute quadrangles covering the area are also shown and identified by the following symbols: A - Fines Creek; B - Sandymush; C - Leicester; D - Clyde; E - Canton; F - Enka.

encompass 2,200 acres. The excavation was to be located within a larger area of no more than 39 square miles which would accommodate surface facilities as well as provide a buffer and control area. In addition, the underground excavation was to be at least 1,150 feet below ground surface to insure an adequate overburden shield. To keep earth pressures from being excessive, the excavation was to be no more than 2,620 feet deep (U.S. Department of Energy, 1986, p. 1-13 through 1-18).

The definition of crystalline rock, the area requirements, and the depth limitations provide an objective set of criteria to use in judging the geologic suitability or non-suitability of a specific rock mass for consideration as a repository site.

SOURCES OF GEOLOGIC DATA

Evaluation of the bedrock suitability was fundamental to the site selection procedure. The screening process used by the Department of Energy to pick out potentially acceptable crystalline rock sites involved an exhaustive literature review of published or otherwise available geologic data. For some areas, detailed geologic work existed, but in the case of the SE-5 area, no comprehensive geologic study had ever been made. Two geologic maps covered the SE-5 area and were used by the Department of Energy. However, they are both non-detailed, regional reconnaissance works (Keith, 1904 [scale 1:125,000]; Hadley and Nelson, 1971 [scale 1:250,000]). These maps are useful in depicting regional relations, but are much too generalized for critical site-specific evaluation. Now, however, detailed field data presented in the companion to this report (Merschat and Wiener, 1988) permit a much more rigorous and thorough geologic review. The following paragraphs compare geologic requirements as defined by the Department of Energy with the actual properties of the site as now documented by the field-based investigation.

COMPARISON OF ROCK TYPES WITH CRYSTALLINE ROCK DEFINITION

Field and laboratory work shows that there are numerous types and varieties of rocks in the SE-5 region (Merschat and Wiener, 1988). To facilitate comparison of the rocks with the Department of Energy's requirements, they are organized here into four major lithologic groups. The four groups are termed:

I. Granitic Gneiss Group
II. Pelitic Metasedimentary Group
III. Amphibolite-Bearing Layered Biotite Gneiss and Schist Group
IV. Aluminous Metasedimentary and Metavolcanic Group

Figure 3 is an outline map showing the distribution of the four groups in the SE-5 area. Table 1 identifies the individual formations that compose each group, lists the component rock types, and identifies each group's outcrop area.

INTRUSIVE IGNEOUS ROCKS

Two classes of rocks are mentioned in the Department of Energy's definition—intrusive igneous rocks and high-grade metamorphic rocks. The entire SE-5 area underwent regional metamorphism at least once. The rock units that evolved from intrusive bodies still retain some relics of their original magmatic nature, but even these relic igneous rocks exhibit a gneissic fabric. Based on mineral composition and other features, only the Spring Creek Granitoid Gneiss of Group I might possibly meet the "intrusive igneous" part of the definition. A narrow band in the northwest corner of the SE-5 area, approximately 3 miles long and averaging about 1 mile wide, is largely underlain by biotite granitic gneiss of the Spring Creek (Merschat and Wiener, 1988, plate 1). However, the Spring Creek is by no means a uniform, monolithic unit. It includes interlayers of undesirable amphibolite and calc-silicate granofels, as well as abundant mylonitic zones. Furthermore, the limited

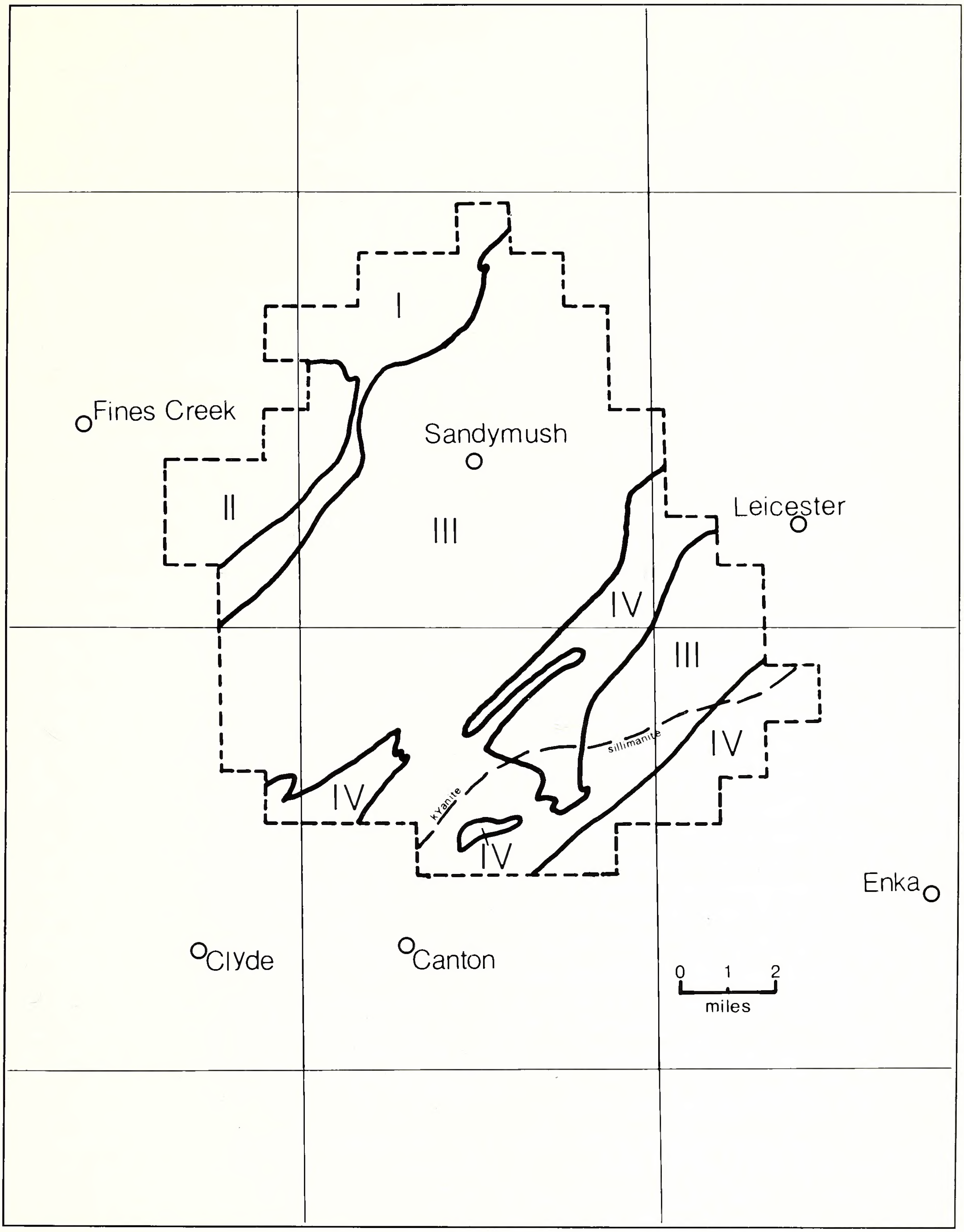

Figure 3. Outline map of the SE-5 area showing distribution of the four major rock groups (see table 1 for description of groups). Kyanite-sillimanite isograd shown by long-dashed line. Geologic data sources: Sandymush and Canton Quadrangles - Merschat and Wiener, 1988; Leicester Quadrangle - Wiener, unpublished mapping; Fines Creek, Clyde, and Enka Quadrangles - reconnaissance mapping, Merschat and Wiener.

extent of the Spring Creek is not sufficient to allow for siting of the needed 2,200-acre underground facility.

The other formation in Group I is the Doggett Gap Protomylonitic Granitoid Gneiss. It also originated as an intrusive igneous rock; however, the unit has been so severely deformed and mylonitized that it now has the attributes of a coarsely foliated gneiss. Further, within the SE-5 area, the 4-mile-long outcrop belt of the Doggett Gap, including its two mapped amphibolite bodies, is nowhere more than 1.2 miles wide. Thus, it too, does not meet the Department of Energy's suitability requirements.

METAMORPHIC ROCKS

The remainder of the SE-5 site is underlain by rocks that come under the part of the crystalline rock definition dealing with metamorphic rocks. Included here are the rocks of Groups II, III, and IV. The Department of Energy's definition states three criteria for judging the acceptability of metamorphic rocks: 1) metamorphic grade; 2) texture; and 3) lithologic character. In the following discussion, these properties of the area's metamorphic rocks are listed for comparison with the Department of Energy's criteria (also see table 2).

Group II. Pelitic Metasedimentary Group (Snowbird Group):

(1) is not metamorphosed to the upper amphibolite facies;

(2) exhibits lepidoblastic (schistose) textures, not granoblastic texture;

(3) is overwhelmingly dominated by pelitic schist.

Thus, when compared with the three criteria for metamorphic rocks, these pelitic rocks obviously do not qualify as acceptable "crystalline rock".

Table 1. *Description of lithologic groups in the SE-5 area*

I. Granitic Gneiss Group. Includes the Spring Creek Granitoid Gneiss and the Doggett Gap Protomylonitic Granitoid Gneiss.

The prevalent rock types are megacrystic and protomylonitic biotite granitic gneiss, mylonitic granitic gneiss, and biotite granitic gneiss. Pervasive mylonitization is especially well developed throughout the Doggett Gap Protomylonitic Granitoid Gneiss.

This group occurs in the northwestern part of the SE-5 area, mainly in Madison County.

II. Pelitic Metasedimentary Group. Includes the Snowbird Group.

Kyanite-garnet-mica schist dominates, with lesser metagraywacke, metaconglomerate, and calc-silicate rock.

These rocks occur in the western part of the area, mainly along the Buncombe-Madison County line in the vicinity of Sandymush Bald and Little Sandymush Bald.

III. Amphibolite-Bearing Layered Biotite Gneiss and Schist Group. Includes the Sandymush Felsic Gneiss and the Earlies Gap Biotite Gneiss.

This is a very heterogeneous group of rocks. It includes layered biotite gneiss, biotite schist, felsic gneiss, abundant interlayered amphibolite, and minor calc-silicate rock.

These rocks underlie the central part of the area. They extend from the Little Pine Creek section of Madison County through the Sandymush community and North Turkey Creek section of Buncombe County, and into the Crabtree Creek and Beaverdam sections of Haywood County.

IV. Aluminous Metasedimentary and Metavolcanic Group. Includes the Ashe Metamorphic Suite.

These rocks are mostly muscovite-biotite gneiss and schist, kyanite-garnet-muscovite-biotite gneiss and schist, biotite-feldspar-quartz gneiss, and sillimanite-garnet gneiss and schist. Minor amounts of several other rock types are also present.

This group occurs in the south and southeastern part of the SE-5 area in both Haywood and Buncombe County.

Group III. Amphibolite-Bearing Layered Biotite Gneiss and Schist Group (Sandymush Felsic Gneiss and Earlies Gap Biotite Gneiss):

Table 2. *Comparison of the SE-5 area's metamorphic rocks with the acceptability requirements of metamorphic grade, texture, and lithologic composition*

METAMORPHIC ROCK GROUP	GRADE	TEXTURE	COMPOSITION
	Are the rocks of sufficiently high metamorphic grade? (Above sillimanite isograd?)	Do rocks exhibit granoblastic texture?	Are rock types acceptable? (Less than 50 percent marble, calc-silicate, and pelitic schist or amphibolite.)
Group II	No - all are below sillimanite isograd.	No - lepidoblastic texture dominates.	No - pelitic schist dominates.
Group III	Almost entirely below sillimanite isograd.	Mostly gneissic lepidoblastic to nematoblastic textures.	Schist and amphibolite compose 10-20 percent of group.
Group IV	All, except three small areas, are below sillimanite isograd.	Lepidoblastic and nematoblastic textures are widespread and locally dominant.	Fifty percent of group is schist.

(1) mostly is not metamorphosed to the upper amphibolite facies;

(2) chiefly exhibits gneissic lepidoblastic to nematoblastic textures rather than granoblastic texture;

(3) includes abundant, widespread schist and amphibolite. Schist and amphibolite are estimated to constitute 10 to 20 percent of the group.

Thus, this group does not qualify as an acceptable crystalline rock, mainly on the basis of criteria 1 and 2. Also, the presence of so much schist and amphibolite, though less than the disqualifying limit of 50 percent, is a significant factor that reduces the group's acceptability.

Group IV. Aluminous Metasedimentary and Metavolcanic Group (Ashe Metamorphic Suite):

(1) has been metamorphosed, in part to lower amphibolite facies, and in part to upper amphibolite facies as indicated by the presence of sillimanite. Upper amphibolite facies rocks of this group are present in only three small separated areas. One area comprises about 1.25 square miles, and another about 1 square mile. The third area covers about 1.5 square miles on the Canton Quadrangle and about 3.5 square miles on the adjoining Enka Quadrangle (figure 3).

(2) exhibits diverse textures, but lepidoblastic (schistose) and nematoblastic textures are widespread and locally dominant;

(3) contains about 50 percent aluminous pelitic schist.

Most of the area underlain by Group IV is metamorphosed below upper amphibolite facies as kyanite, not sillimanite, is present (note location of sillimanite-kyanite isograd in figure 3). The rocks in only three, small, isolated areas attained upper amphibolite facies. However, in these areas too much schistose and non-granoblastic material is present to meet the stated criteria. Furthermore, two of the areas are not nearly extensive enough to meet the design requirement of 2,200 acres (about 3.4 square miles). The third, and largest area, is along the southeast border of the SE-5 site where there is not enough space for the requisite buffer and control zone.

OTHER NEGATIVE FACTORS

In addition to the failure of strata in the SE-5 area to adequately meet the Department of Energy's crystalline rock criteria, several other geological factors indicate that the area is not suitable for use as a high-level nuclear waste repository. These include pervasive foliation sur-

faces, abundant joints and fractures, mylonitic rocks, the likelihood of deep circulation of groundwater, and the mountainous terrain of the area. Also, tungsten, a strategic and critical commodity, was discovered in the area. This new find should be evaluated prior to committing the area to a single-use purpose.

Foliation

Subsequent to their original deposition or intrusion, rocks in this region underwent several episodes of deformation and metamorphism. Each event left its own imprint on the rocks, usually in the form of various folds and faults as well as abundant and widespread foliation planes. Each of these ubiquitous foliation planes defines a mechanical weakness in the rock mass and poses a potential, troublesome slip surface during design, construction, and maintenance of any bedrock excavation.

The mica-rich rocks, or schists, have the best developed and most closely spaced foliation planes. Foliation in the gneissic units is more irregular and more coarsely spaced. But even in these rocks, the foliation surfaces are planes of mechanical weakness.

Joints

Joints, as well as non-systematic fractures, exist at almost every outcrop in the SE-5 area and certainly extend some distance into the earth. Shallow core drilling for foundation and road design in nearby places frequently reveals weather-stained fractures at depths of 200 feet or more. Several 200- to 300-foot-deep road cuts in western North Carolina also show that joints occur well below the original ground surface. Two deep cuts near the SE-5 area where joints are present are the extensive excavations east of Marshall along U.S. 25 and U.S. 70 in Madison County, and the Interstate-240 cut through Beaucatcher Mountain in Asheville. Some joints must also be present much further below the surface based on the known deep circulation of groundwater in the general region (see following discussion on groundwater circulation).

Joints are undesirable for two reasons. First, they are discontinuity surfaces with zero tensile strength and may thereby contribute to failure of an excavation. Second, in hard, coherent, otherwise impermeable rocks, joints provide openings and conduits for groundwater accumulation and movement. Even if persistent joints are not already open and permeable to underground water, it seems inevitable that the creation and maintenance of extensive subsurface openings, such as necessary for a deep subsurface repository, would lead to the formation or propagation of joints (Konya and Walter, 1985).

Mylonitic Rocks

Mylonites and protomylonites are locally present throughout the area. These rocks are indicative of ancient faults or deformation zones. They are characterized by their anisotropic, anastomosing, statistically planar fabric and the flattened, elongated and recrystallized nature of the constituent mineral grains. This planar fabric is a significant weakness that may also lead to unstable conditions in excavations -- a significant concern for an underground repository.

Evidence For Deep Circulation of Groundwater

Over long periods of time circulating groundwater has the very undesirable potential to leach waste radioactive material and carry it well beyond the confines of a repository's controlled area. This contaminated water may thus diffuse into the region's groundwater supply or ultimately enter local streams and rivers. Thus, it is essential that a repository be impervious to through-circulating groundwater.

Two lines of evidence indicate that groundwater circulates to considerable depth in the region. Some water wells in the Blue Ridge and Piedmont are known to produce water from depths of 1,200 feet or more (Daniel, 1987). This is direct evidence for deep circulation, undoubtedly through persistent joint openings (Daniel, 1987).

A slightly less direct line of evidence is based on the presence of warm-water springs in the town of Hot Springs, North Carolina (Trapp, 1970). The town is in northwestern Madison County, within a dozen miles of area SE-5. The temperature of the flowing spring water is about 100°F (Oriel, 1950). The comprehensive geologic report by Oriel (1950) and a more recent analysis by Hobba and others (1979), support the concept of geothermal heating of deep-circulating meteoric water in the Hot Springs area. Hobba and others (1979, p. 20) estimated the water circulates to a depth of at least 4,000 feet. Based on a presumed geothermal gradient of about 70 feet per 1°F, plus a substantial allowance for cooling as the hot water rises toward the surface, Oriel (1950, p. 58) concluded that the meteoric water might circulate as deep as 5,500 to 6,000 feet. North Carolina Geological Survey well-file information for a 3,200-foot drill hole near Spruce Pine, North Carolina, indicates geothermal heating to be about 1°F per 114 feet. Use of this value leads to an estimated minimum circulation depth of 5,700 feet in the Hot Springs area. To allow for cooling as the water returns back to the surface, an even greater circulation depth to reach warmer rocks is necessary.

Clearly then, groundwater is able to circulate to considerable depth in places near the SE-5 area. This indicates that the rock mass in the area is not as impervious to groundwater as might be first assumed. This poses a very serious question about the hydrologic suitability of any large underground site in the western Blue Ridge area.

Mountainous Terrain

The steep, mountainous terrain of area SE-5 imposes important constraints on the siting of an underground nuclear waste repository. The peak elevation within the SE-5 area is 5,152 feet on Sandymush Bald; the lowest is about 2,100 feet along Sandymush Creek. Within the area, elevation differences are as great as 2,800 feet in less than 2.5 miles of surface distance. These great elevation differences make it virtually impossible to locate a 2,200-acre underground site so that it would be entirely within the maximum and minimum depth requirements of 2,620 and 1,150 feet, respectively. The terrain limitation is clearly an adverse condition that permits little flexibility in selecting the configuration or location of a large underground facility in the area.

Tungsten

Stream sediment samples collected from the Sandymush and Canton Quadrangles area revealed the widespread presence throughout the central part of the area of the mineral scheelite. Scheelite is not only an unusual mineral, but also a major ore mineral of the metal tungsten. Tungsten is a strategic and critical commodity that is in short supply in domestic deposits, thereby forcing the United States to import much of its annual consumption. From 1983 through 1987, the United States' net import reliance compared to apparent consumption was about 68 percent (U.S. Bureau of Mines, 1988, p. 172-173). This new discovery in the SE-5 area warrants a follow-up investigation to determine the extent of the tungsten resource. Certainly, it is not in the country's best interest to preempt the area for a single-purpose use, thereby effectively removing a potential critical mineral resource from the Nation's limited inventory.

CONCLUSION

Scientific information collected during the detailed geologic investigation of the Sandymush and Canton Quadrangles (Merschat and Wiener, 1988) is used to evaluate the suitability of the U.S. Department of Energy's SE-5 area for an under-

ground, "crystalline rock", high-level radioactive waste repository. The area's rocks are mostly layered metamorphic types that do not meet the well-defined criteria for acceptable crystalline rock. Other factors also indicate the area is not suitable. They are: the presence of ubiquitous foliation surfaces and joints in all of the rocks; mylonite and protomylonite zones; the possibility of deeply circulating groundwater; a geographic setting in mountainous terrain; and the possibility of a new tungsten resource. Thus, failure of the area's rocks to meet acceptability criteria, along with numerous other geologically negative factors, makes the area unsuitable for consideration as an underground, high-level nuclear waste repository.

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